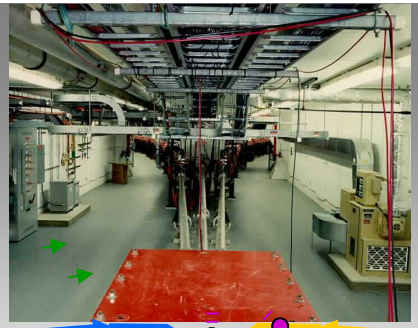
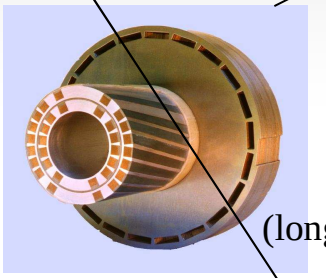
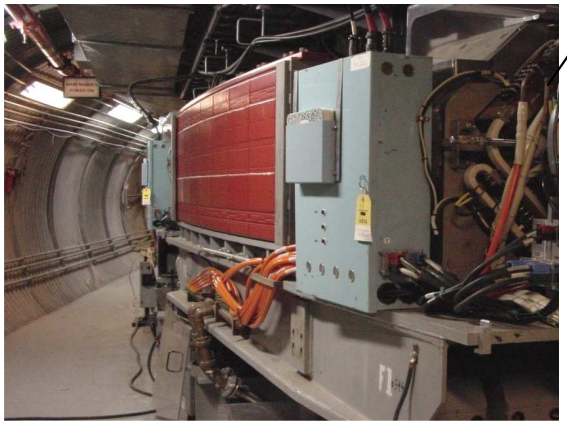
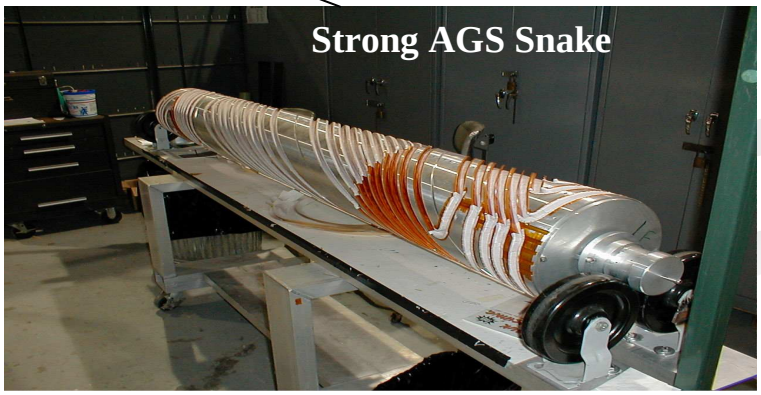
# Run-6 Overview









***BRAHMS(p)***

**Absolute Polarimeter (H jet)**

RHIC pC Polarimeters

Siberian Snakes

***PHENIX (p)***

**Spin flipper**

***STAR (p)***

Spin Rotators
(longitudinal polarization)

Spin Rotators
(longitudinal polarization)

Solenoid Partial Siberian Snake

LINAC

BOOSTER

Pol. $H^-$ Source

**Helical Partial Siberian Snake**

**AGS**

200 MeV Polarimeter

AGS Polarimeters

**Strong AGS Snake**

# 2005 Shutdown: Major Upgrades

- RHIC ring vertical realignment
- Additional NEG coating in warm regions, bringing total to 430m covered in the warm sections..
- Lattice for lower injection energy ( $G\gamma$=45.5 ) to provide better polarization matching for AGS-to-RHIC transfer
- Multiple tools for the emittance measurement ( polarimeter target, improved IPM, ATR line flags, jet luminescence monitor)
- BPM electronics upgrade
- New RampEditor.
- STAR detector shielding in the tunnel
- Injection kicker upgrade to provide shorter rise time.
- IR4 and IR8 cryostat measurements to understand the source of 24h orbit variations.

# RHIC Run-6 Timeline

- 1 Feb – Start of the Run-6. Start of the cooldown to liquid He temperatures.
- 12 Feb - End of cooldown and PS tests
- 5 Mar – Start of the 100 GeV Physics Run.
  Participating experiments: STAR and PHENIX.
  **PHENIX** – radial pol ; **STAR** – long pol
- 6 Apr – **PHENIX** – radial pol ; **STAR** – vertical pol
- 14 April –21 April – unscheduled shutdown (investigation of electric accident)
- 26 Apr – **PHENIX** – longitudal pol; **STAR** – vertical pol
- 10 May – **PHENIX** – longitudal pol; **STAR** – longitudinal pol
- 5 Jun – End of 100 GeV run. (12 weeks total )
- 5 Jun-6 Jun, 11 GeV accelerator development
- 6 Jun – Start of 31.2 GeV Physics Run.
  Participating experiments: STAR, PHENIX and BRAHMS
  **PHENIX** – longitudal pol; **STAR** and BRAHMS– vertical pol
- 20 Jun - End of 31.2 GeV Run. (Two weeks total)
- 20 Jun – 26 Jun. 250 GeV accelerator development
- 26 Jun - 30 Jun warm-up to liquid N temperatures.
- 30 Jun - End of Run-6. (21.2 weeks of cryo operation)

# Run-6 sub runs

| Beam energy | 100 GeV | 11 GeV | 31.2 GeV | 250 GeV |
|---|---|---|---|---|
| Purpose | Physics operation | Machine test | Physics operation | Machine test |
| Time | 12 weeks | 1 day | 2 weeks | 1 week |
| Participating experiments (polarization orientation used) | PHENIX, (rad & long), STAR (vert & long) | | PHENIX, (long), STAR, BRAHMS (vert) | |

# Physics run lattices

Beta* configuration (in meters):

| | IP6 | IP8 | IP10 | IP12 | IP2 | IP4 |
|---|---|---|---|---|---|---|
| Injection | 10 | 10 | 10 | 10 | 10 | 10 |
| Store, 100 GeV | 1 | 1 | 10 | 10 | 10 | 10 |
| Store, 31.2 GeV | 3 | 3 | 10 | 10 | 3 | 10 |

Lattice modifications:

- minimized excursion of dispersion function in IR6 and IR8 in the store at 100GeV
- decreased gamma_t lattice at the injection

Working points: (0.72-0.73) box at the injection; (0.68-0.695) box at the store
Tune swing done: 100GeV: at the very end of the acceleration, but before final beta-squeeze part of the ramp
31.2GeV: right before the last stone of the ramp

# Machine setup

- Achieved in record 3 week time between end of the cooldown and the start of the Physics run.
- Even this period can be improved, taking account considerable machine downtime during the setup stage.
- Blue beam injection development and initial tune/decoupling feedback preparations were done already on the cooldown stage (after Blue ring was ready).
- Application of tune/decoupling feedback for the ramp development, from the very beginning.

  Beam delivered to the store on the second ramp attempt!

# Polarized protons performance at 100 GeV (last three runs)

| Parameter | Unit | 2004 | 2005 | 2006 |
|---|---|---|---|---|
| No. of bunches | -- | 56 | 106 | 111 |
| bunch intensity | $10^{11}$ | 0.7 | 0.9 | 1.35 |
| β* | m | 1 | 1 | 1 |
| emittance | mm mrad | 18 | 28 | **18** |
| peak luminosity | $10^{30}cm^{-2}s^{-1}$ | 6 | 10 | **35** |
| average luminosity | $10^{30}cm^{-2}s^{-1}$ | 4 | 6 | **20** |
| collision points | -- | 4 | 3 | 2 |
| time in store | % | 41 | 56 | **46** |
| average polarization, store | % | 46 | 47 | **65%** |

Luminosity gain in run-6:

2.2 X 1.5 = 3.3

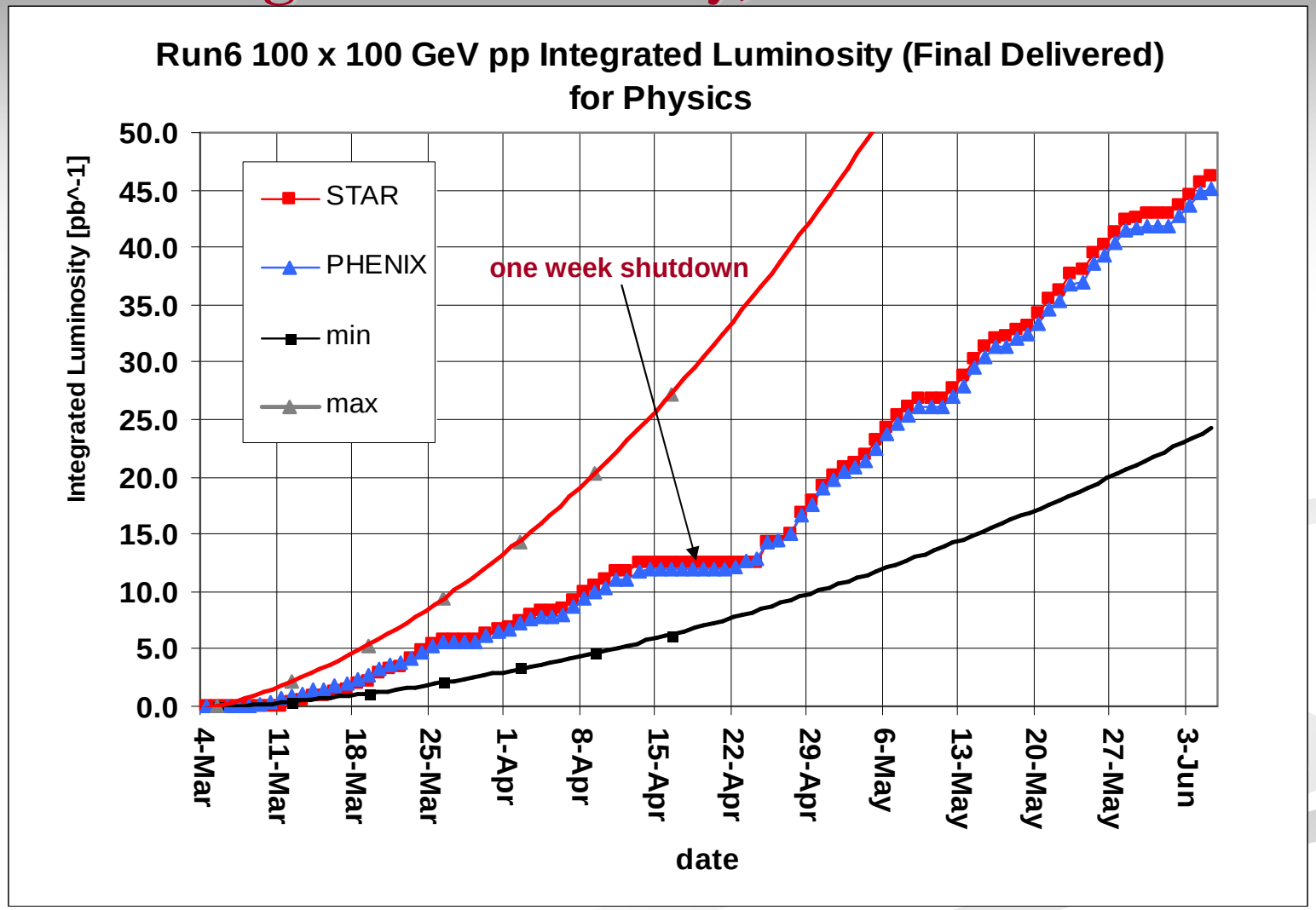
Increased bunch intensity

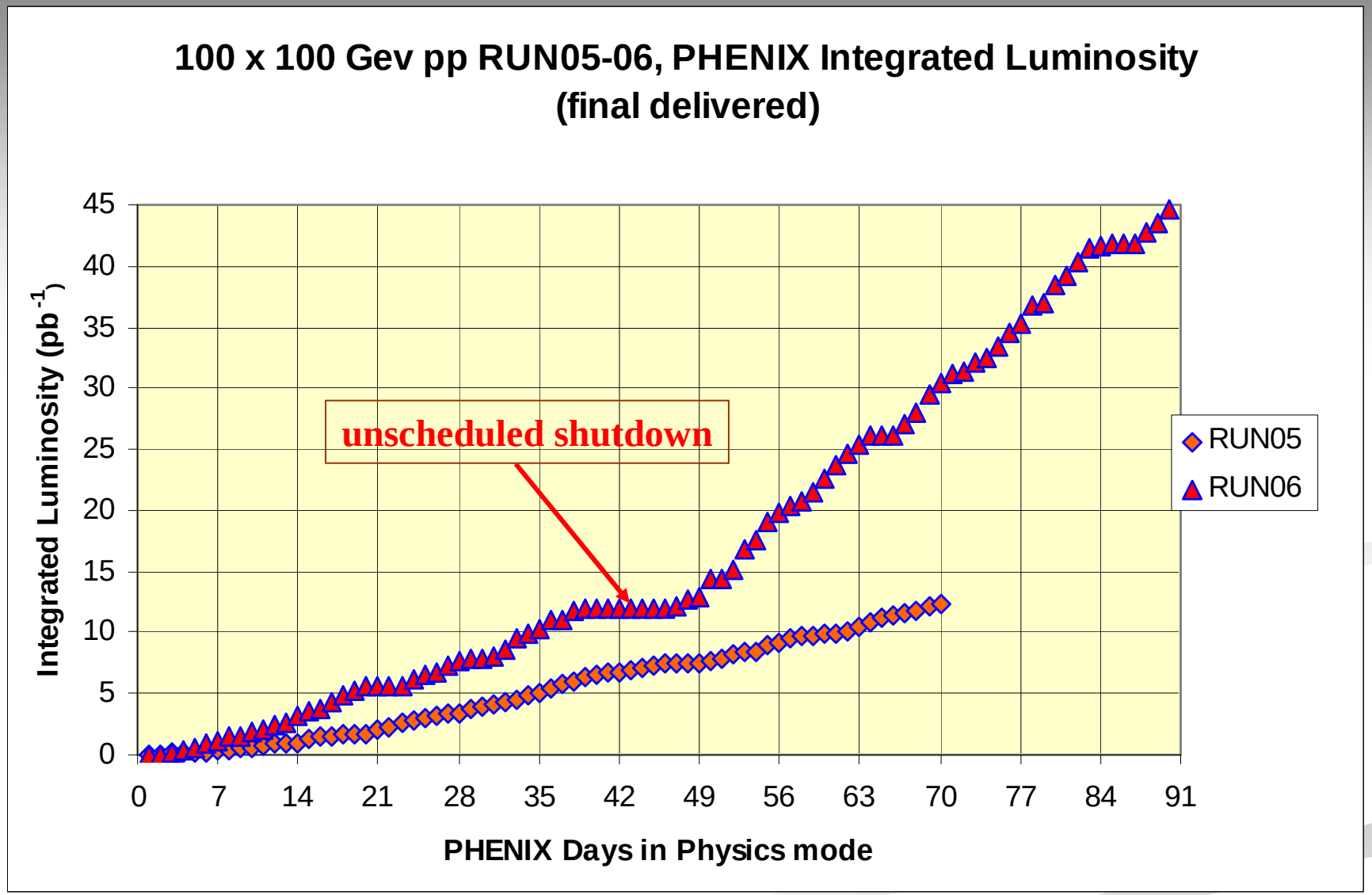
Improved emittance control

AGS cold snake: polarization

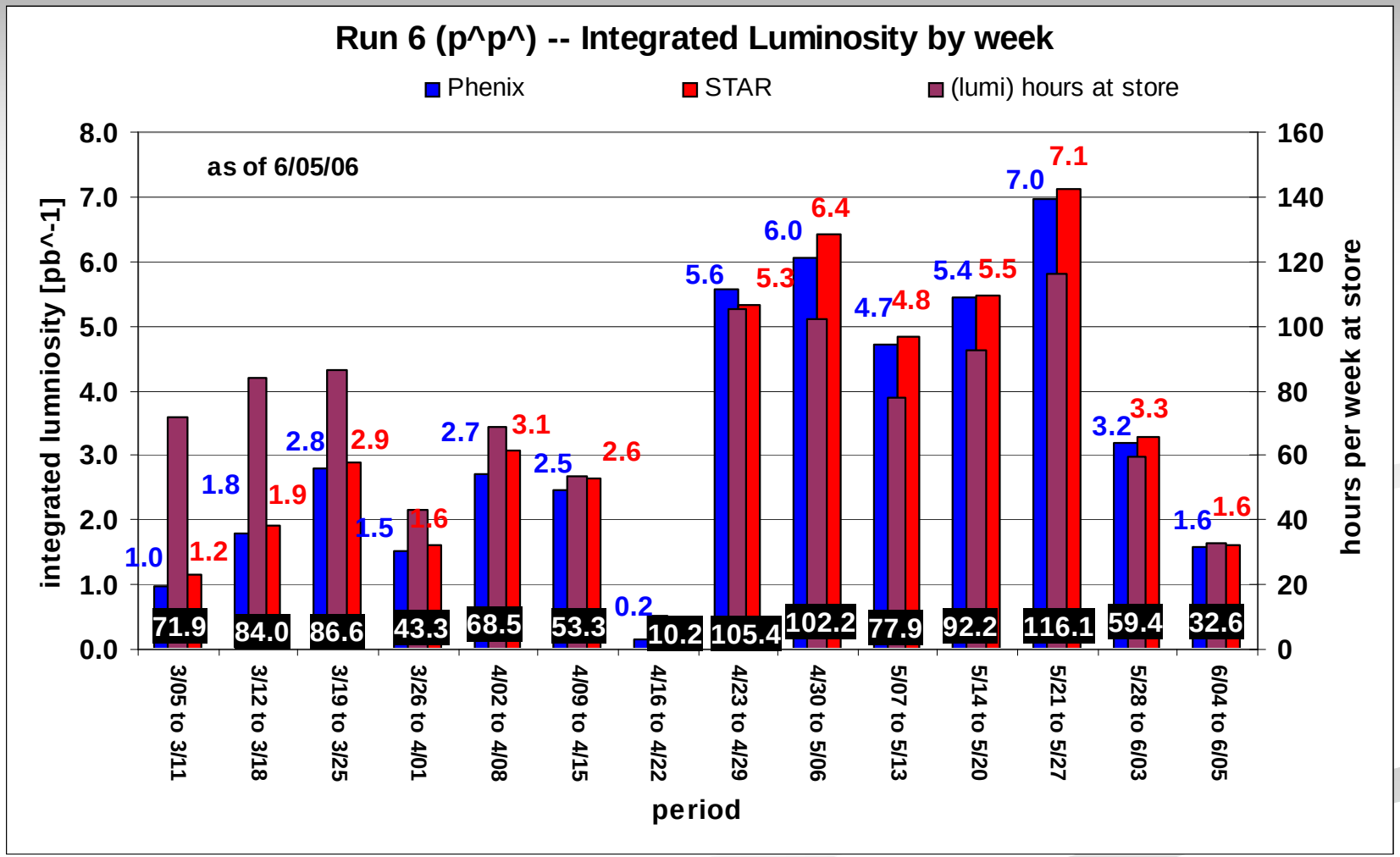
Reduced number of collision points

# Integrated luminosity; 100 GeV run




100 x 100 Gev pp RUN05-06, PHENIX Integrated Luminosity
(final delivered)
Integrated Luminosity (pb-1)
45
40
35
30
25
20
15
10
5
0
0
7
14
21
28
35
42
49
56
63
70
77
84
91
PHENIX Days in Physics mode
unscheduled shutdown
RUN05
RUN06

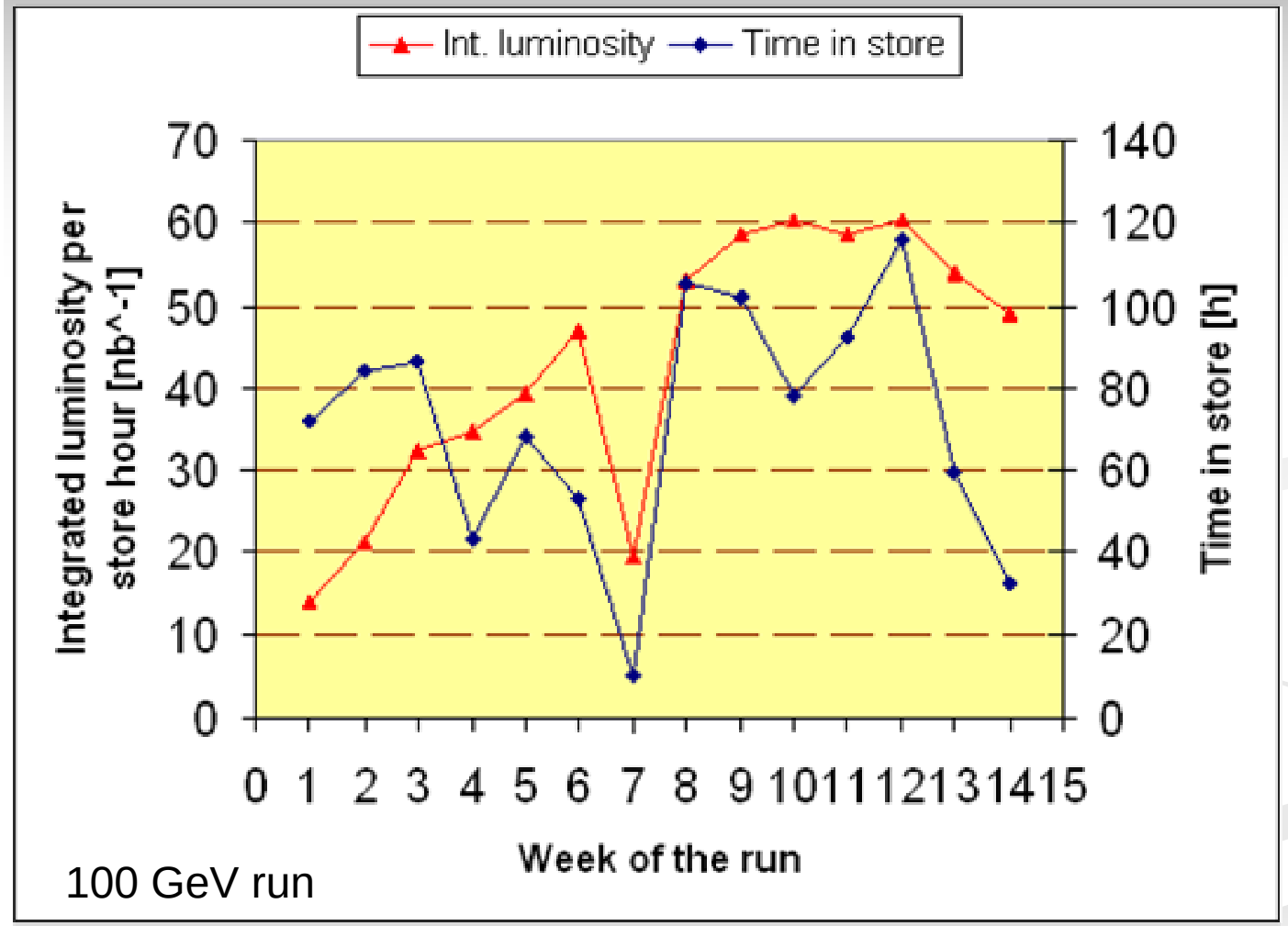
# Integrated luminosity by week; 100 GeV run



# Injector performance

- Much of this run success is due to considerable gain in the injector performance
- Dual snake technique (3 Tesla superconducting helical dipole snake + 1.5 Tesla warm helical dipole snake) was successfully commissioned in the AGS in 2006
- AGS routinely provides 1.5-1.6x$10^{11}$ 23 GeV protons with 60%-65% polarization for the injection into RHIC.
- Small transverse emittances in both planes, ~10-15π mm*mrad, also benefited the improvements of RHIC luminosity

# Average integrated luminosity per store hour and Time in store



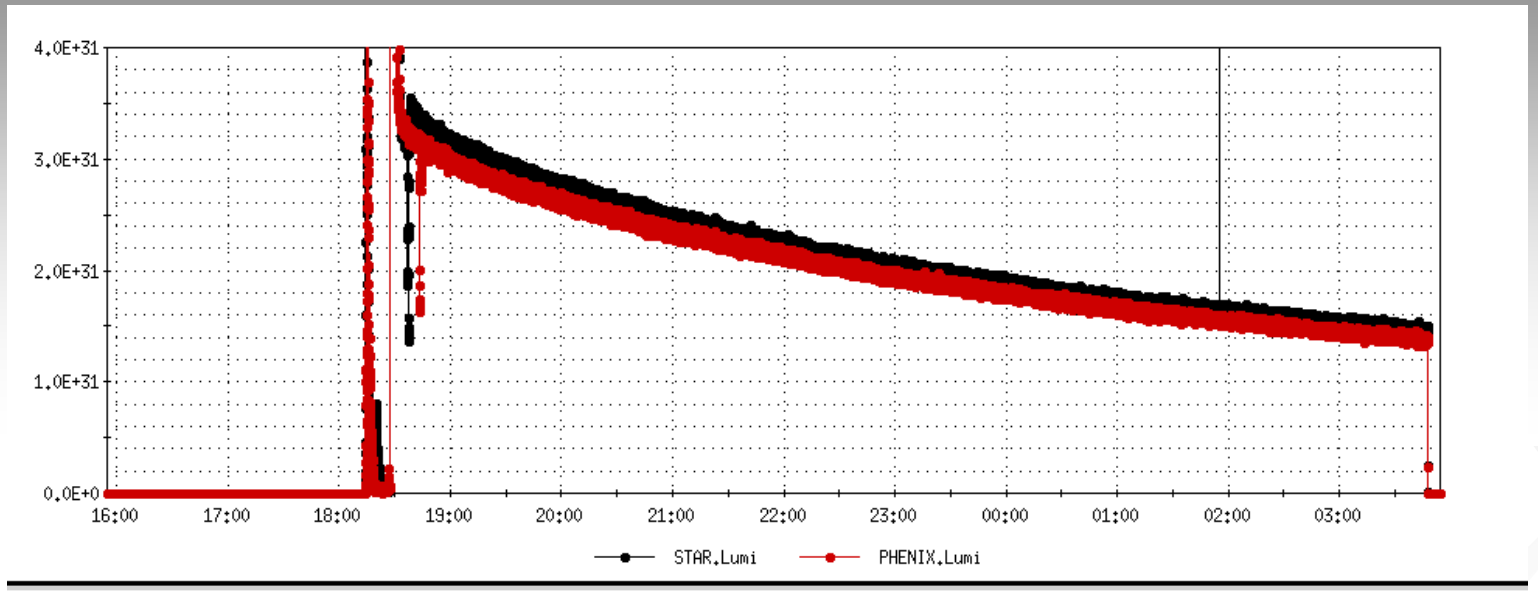

- 8 weeks luminosity improvement period
- 7th week: ~1 week shutdown. Arc flash incident investigation
- Machine reliability problems in the middle and at the end of the run
- Luminosity slides at the end of the run due to longer stores

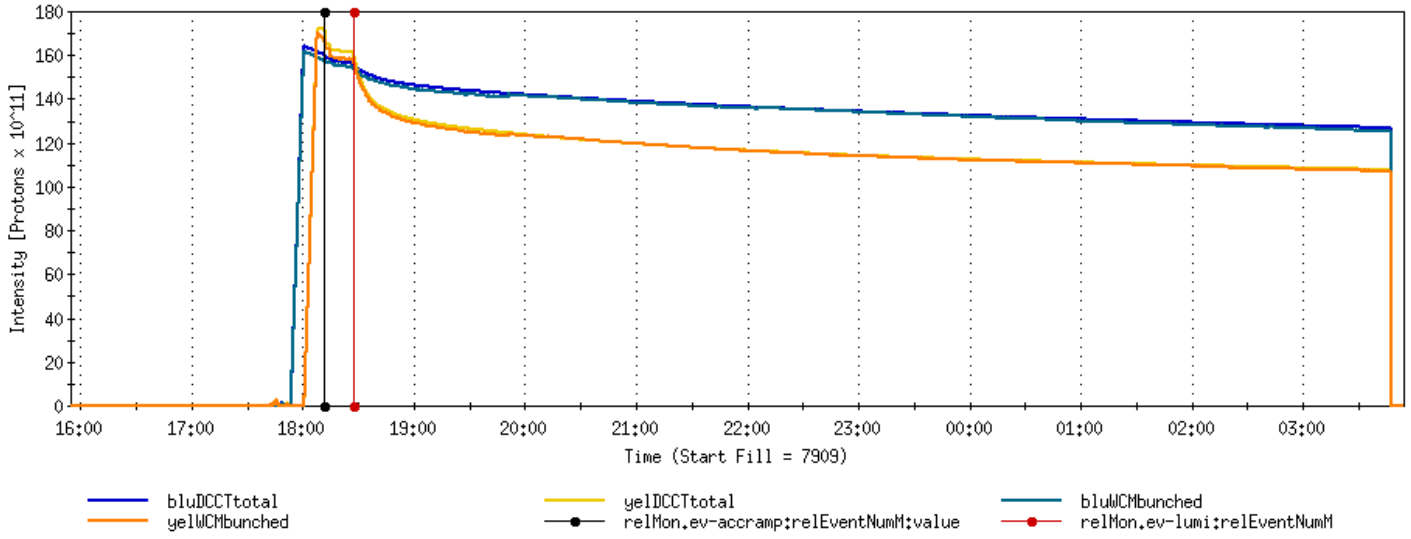
Delivered luminosity integral:
46 $pb^{-1}$ at 100 GeV
350 $nb^{-1}$ at 31.2 GeV

# Luminosity improvement steps during 100 GeV run

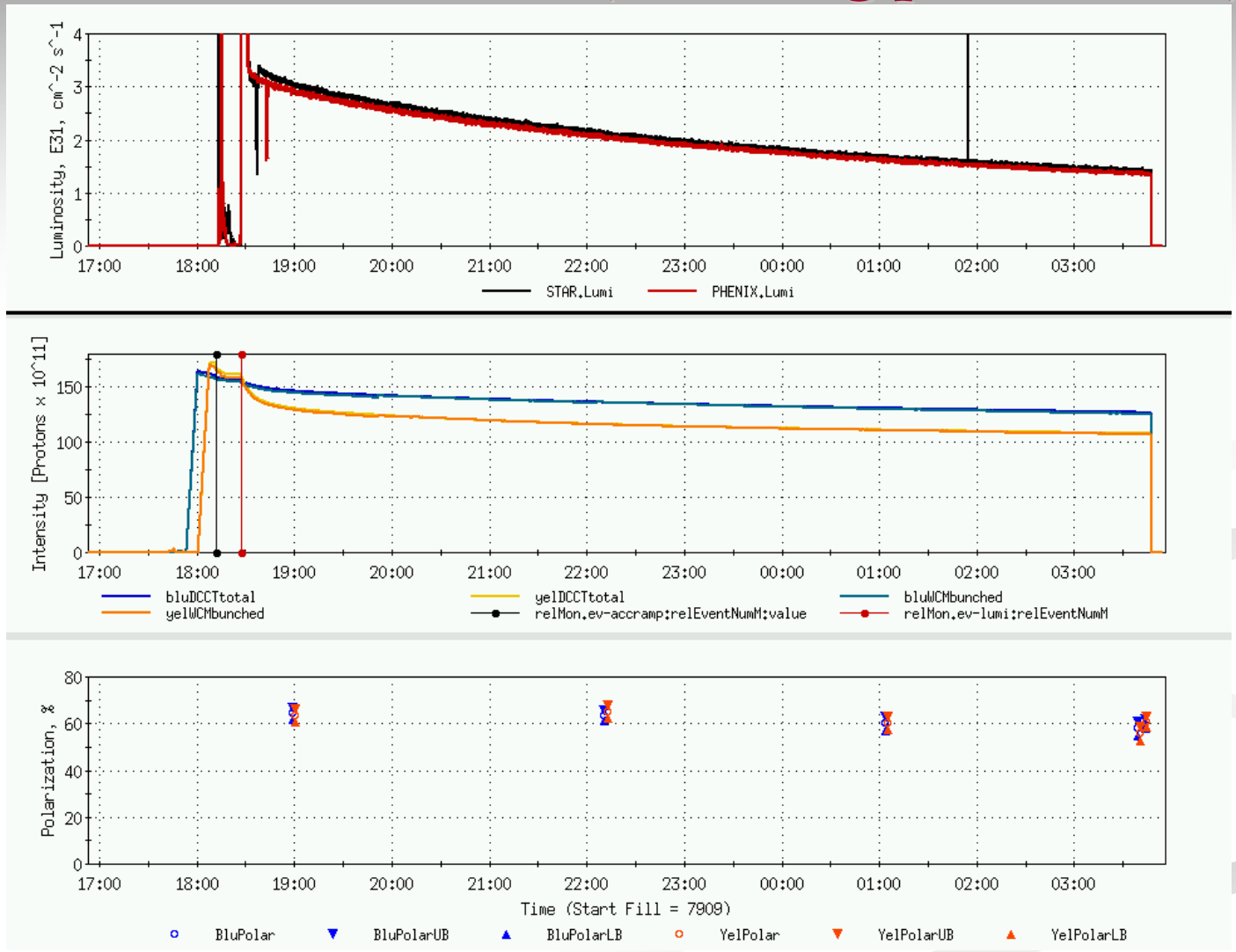
- Improving (reducing)  the emittance from the injectors.
- Increasing number of bunches (54 -> 111)
- Separating Blue and Yellow working points.
- Improving synchro loop, tightening longitudinal phase on the ramp.
- Switching Blue and Yellow working points.
- Increasing bunch intensity (from 1e11 to 1.5-1.6e11 in injected bunches)

# Golden store #7909 of 100 GeV run



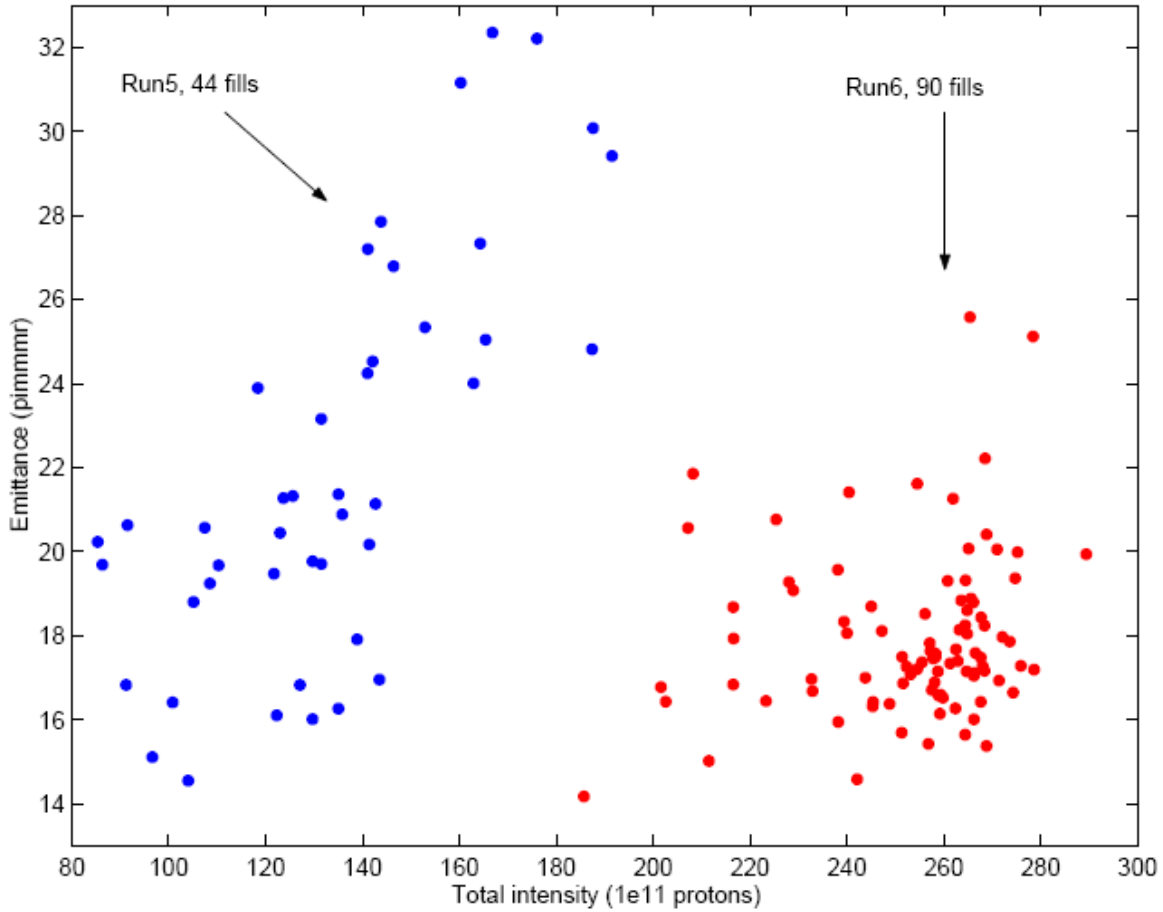



# Golden Store #7909 (including polarization)



# Transverse emittance

S.Y.Zhang




Improved transverse emittance control was important item at this run.

During the run the improvements to achieve smaller transverse emittance were done both in the injectors and in the RHIC:

- Transverse scraping in Booster
- Strict control of emittance from AGS (golden values)
- appropriate choice of working point (to avoid coherent beam-beam)
- keeping bunch length long enough

Helped by vaccuum system improvements:

- additional NEG pipe coating (180m) added between the runs
- upgrade in cold region vacuum

# 100 GeV run: Luminosities and transverse emittances

Improved transverse emittance control was important item at this run

During the run the improvements to achieve smaller transverse emittance were done both in the injectors and in the RHIC:

- Transverse scraping in Booster
- Strict control of emittance from AGS (golden values)
- appropriate choice of working point (to avoid coherent beam-beam)
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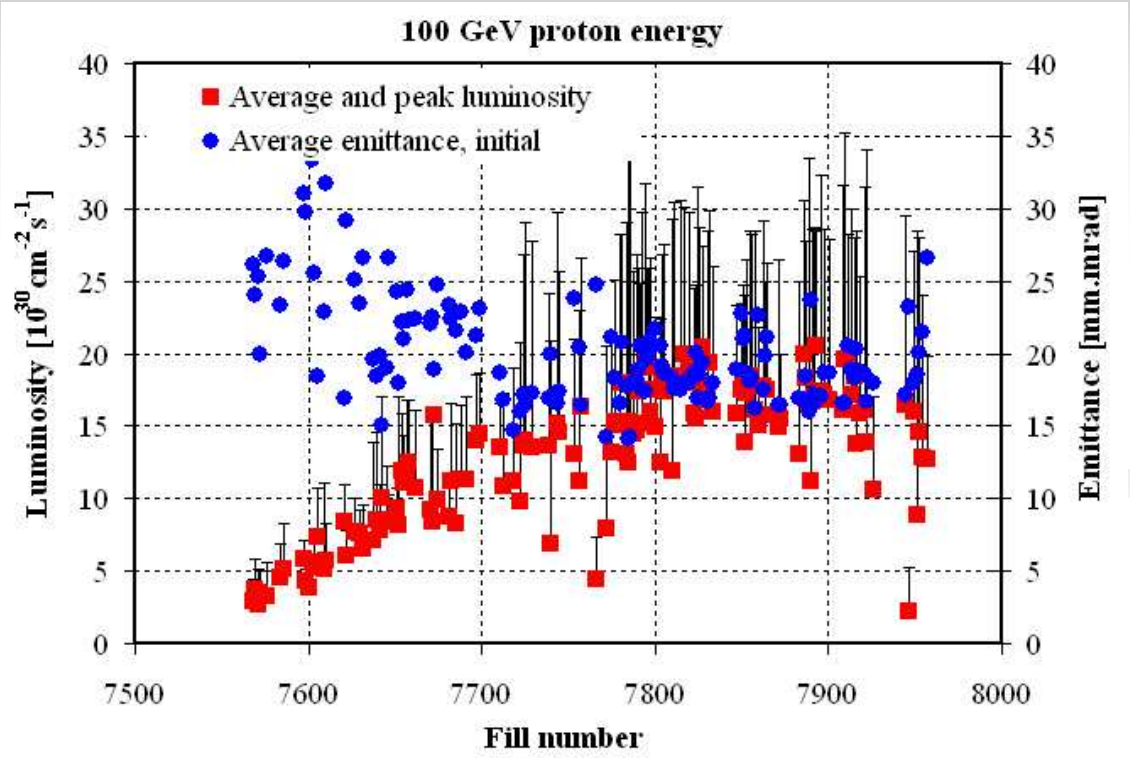
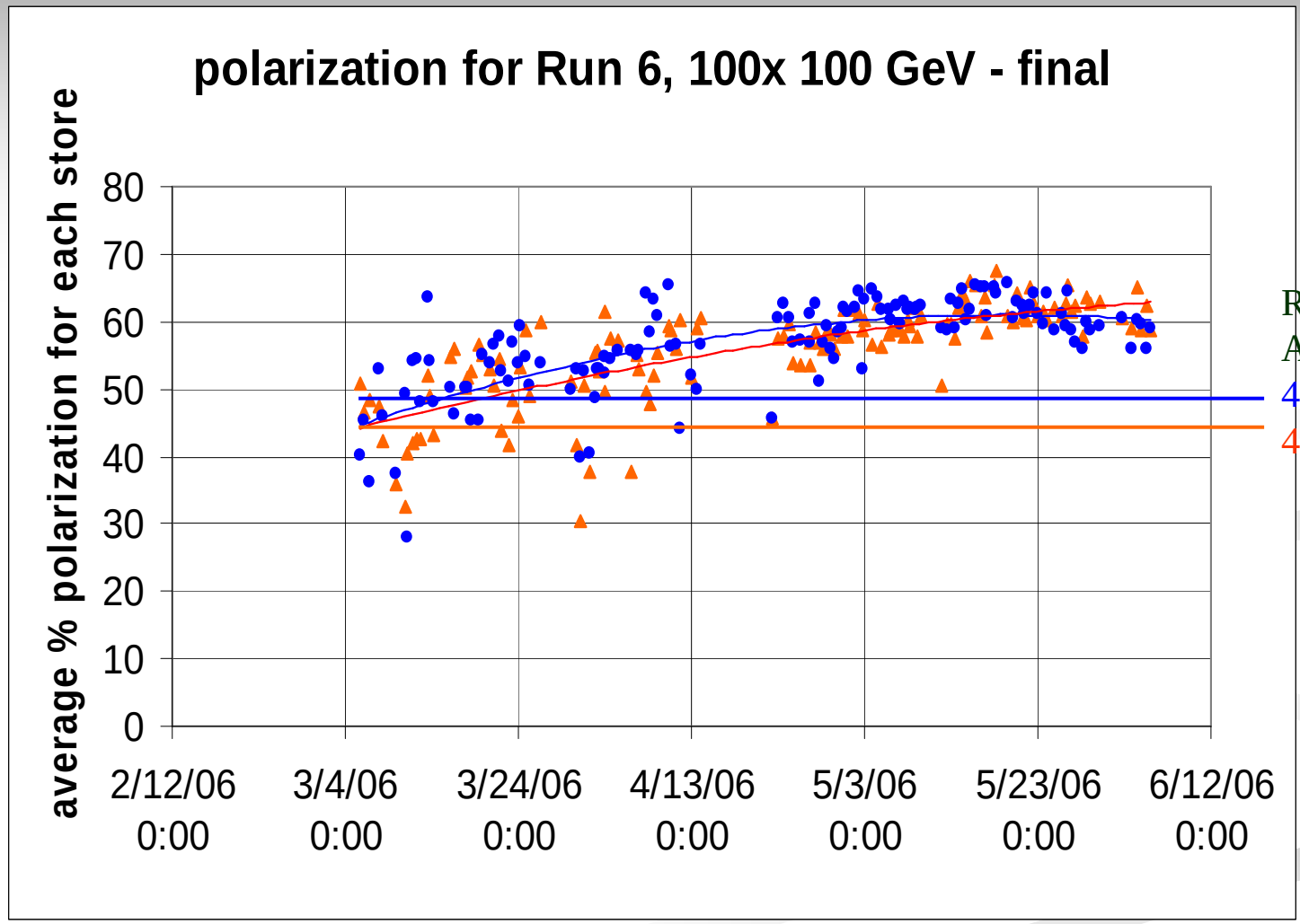



W.Fischer

# Polarization during 100 GeV run



# Polarization preservation

Polarization transmission in RHIC close to 100% (i.e. no polarization loss during the acceleration).

Siberian Snakes work well!

Main factors important for the polarization preservation:

- **Optimal Snake current setting.** To avoid the deviation of spin tune from ½ and corresponding shift in the position of high order spin resonances)
- **Betatron tune control.** To avoid the depolarization caused by ¾ and 7/10 high order spin resonances.
  - Tune+decoupling feedback system was applied succesfully on the machine setup stage.

- **Vertical orbit control.** To minimize the strength of ¾ spin resonance
  - Whole machine vertical realignment was done before the run.
  - Improved BPM system.
  - orbit rms <0.5mm

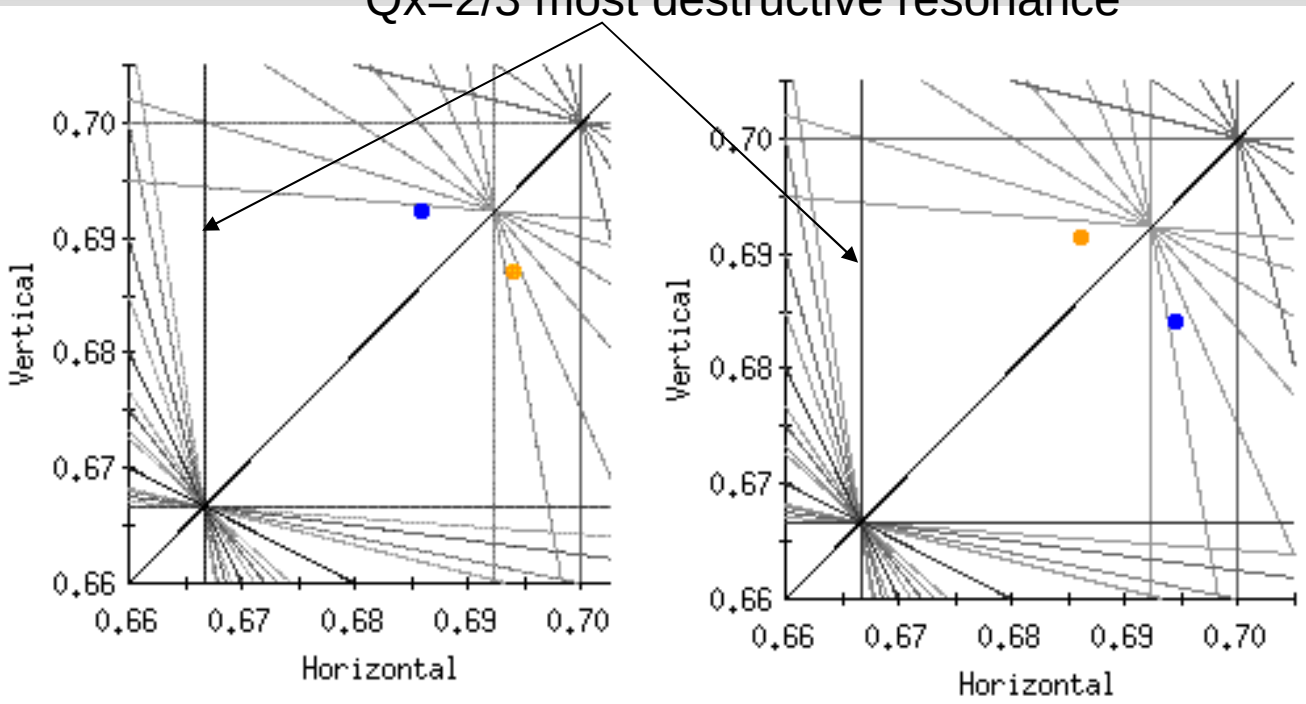
# Rotator and Snake setup

- Snake setup included:
  - Snake scans at the injection (on the machine set up stage)
  - Additional inner snake PS current scans to maximize polarization preservation during the Physics run.

- Rotator setup.
  - Rotator reconfiguration in several steps with beam in the store, making required orbit and tune correction.
  - Propagate the tune and orbit correction to the ramp. (Nevertheless further orbit correction was required in all stones of the rotator ramp.)
  - ~8h of beam work
  - Continued working point adjustments at the beginning of 2-4 following stores to achieve optimal lifetime.
- Rotator and Snakes control was included into the Ramp Editor.

# Store working points

Qx=2/3 most destructive resonance




Old setting




New setting

# Factors limiting machine performance

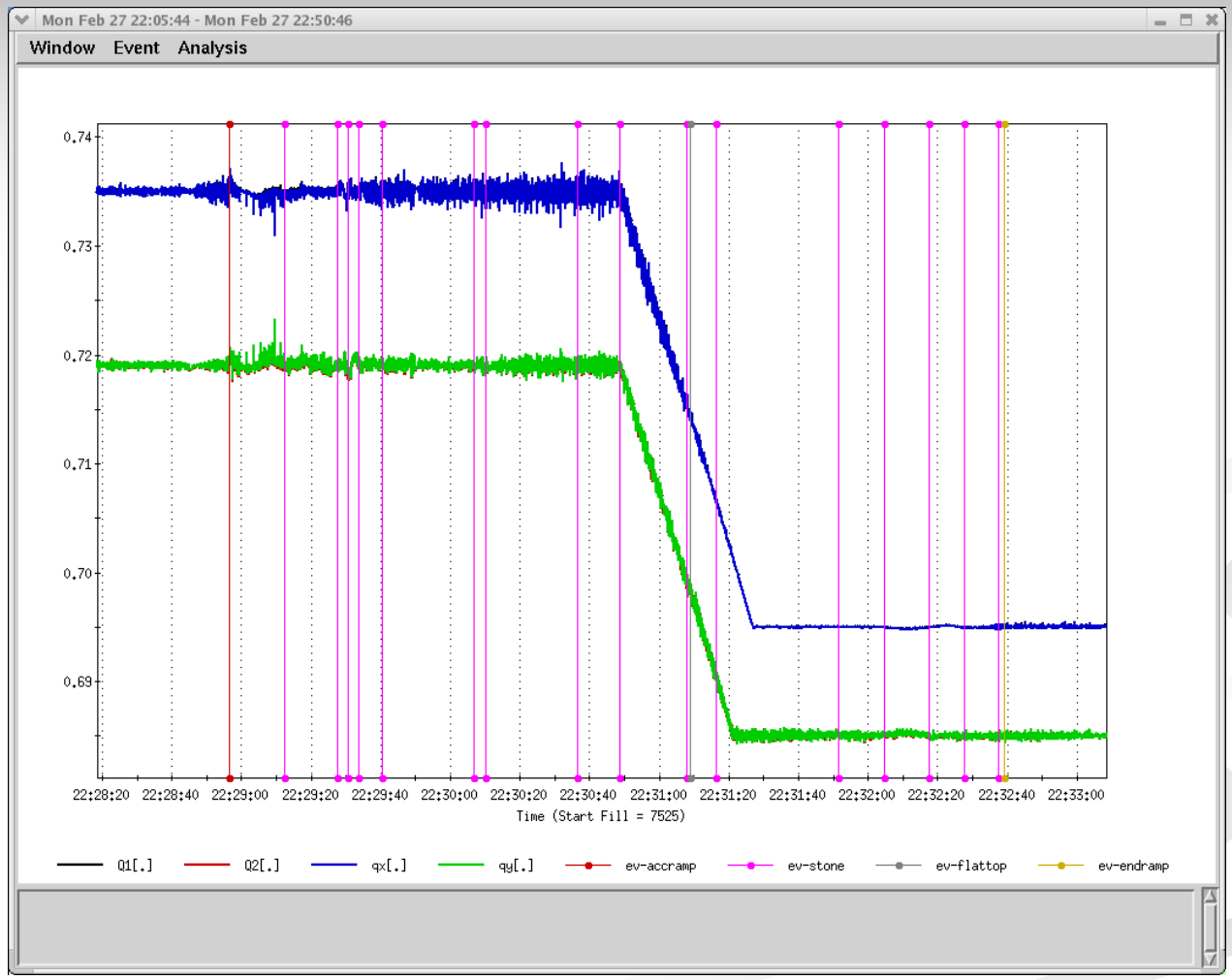
- Store lifetime:
  - $Q_x$=2/3 resonance
  - beam-beam effects
  - large momentum spread
- Factors affecting transverse emittance:
  - small longitudinal emittance and higher beam intensity (enhanced electron cloud effect)
  - emittance increase on the ramp (?)
- Deterioration of ramp transmission with the beam intensity
- Beam oscillations with parasitic frequencies 10Hz, 60Hz, … (coming from cryo and power supply systems)

# Major operation achievements

- Successful application of tune/decoupling feedback for the initial ramp development.
- Fast collimation.
- Regular orbit correction at the beginning of the store (before the cogging) to provide the store reproducibility against 24h orbit variation.
- IR nonlinear corrections: used not only at the store but also on the ramp (after the beta-squeeze).
- 2/3 resonance correction
- Successful demonstration of “quad pumping” technique to provide better AGS-to-RHIC longitudinal emittance matching. Unfortunately, could not be effectively used because of the transverse emittance deterioration.
- Developed Beam Transfer Function measurement diagnostic.
- Rotator reconfiguration (done 5 times during the run).

  Takes 8h + 2-3 stores.

# Betatron tunes on the ramp with the Feedback on



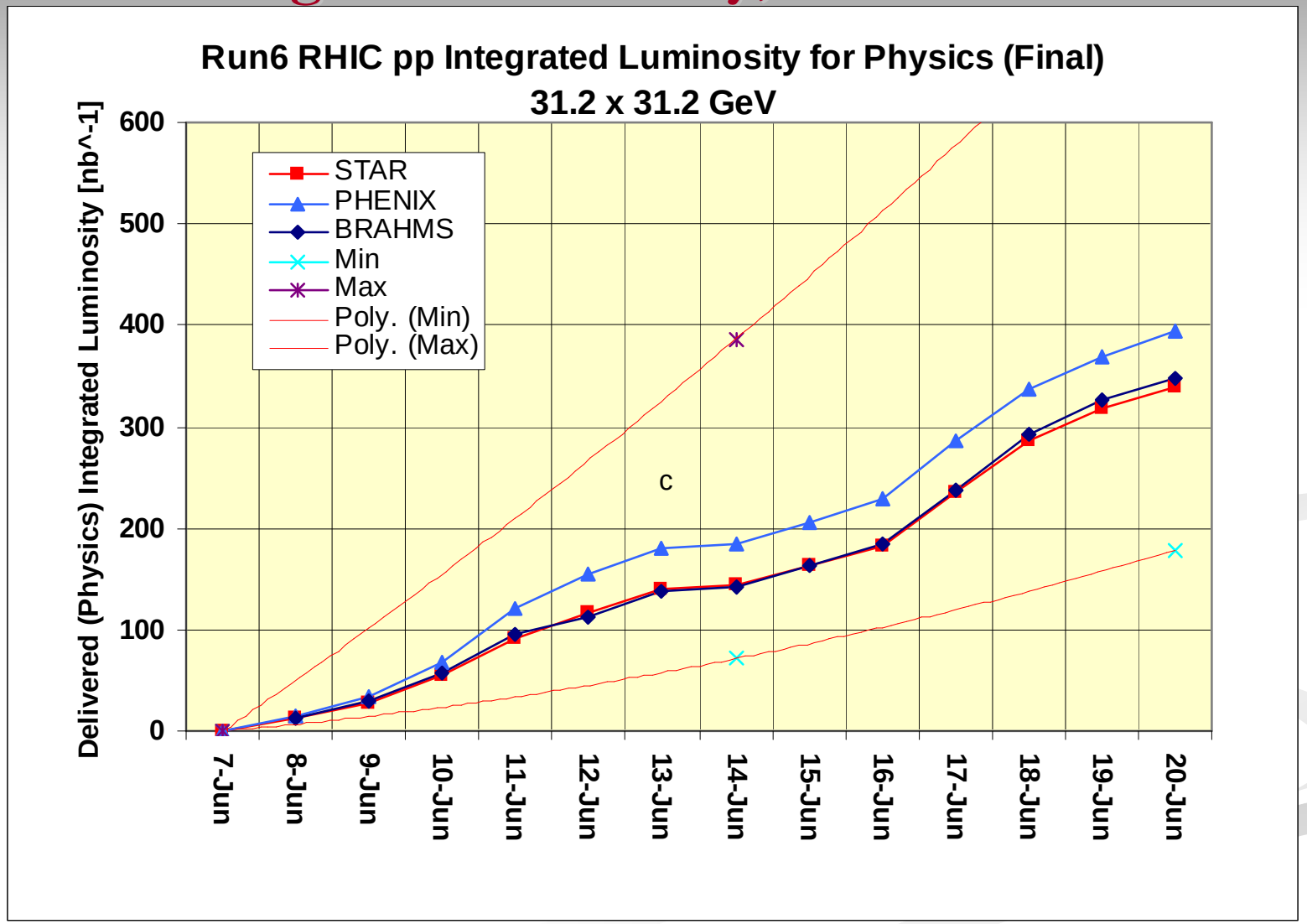
# Some of the remaining operation issues

- Reduce machine downtime, increase the time in the store.

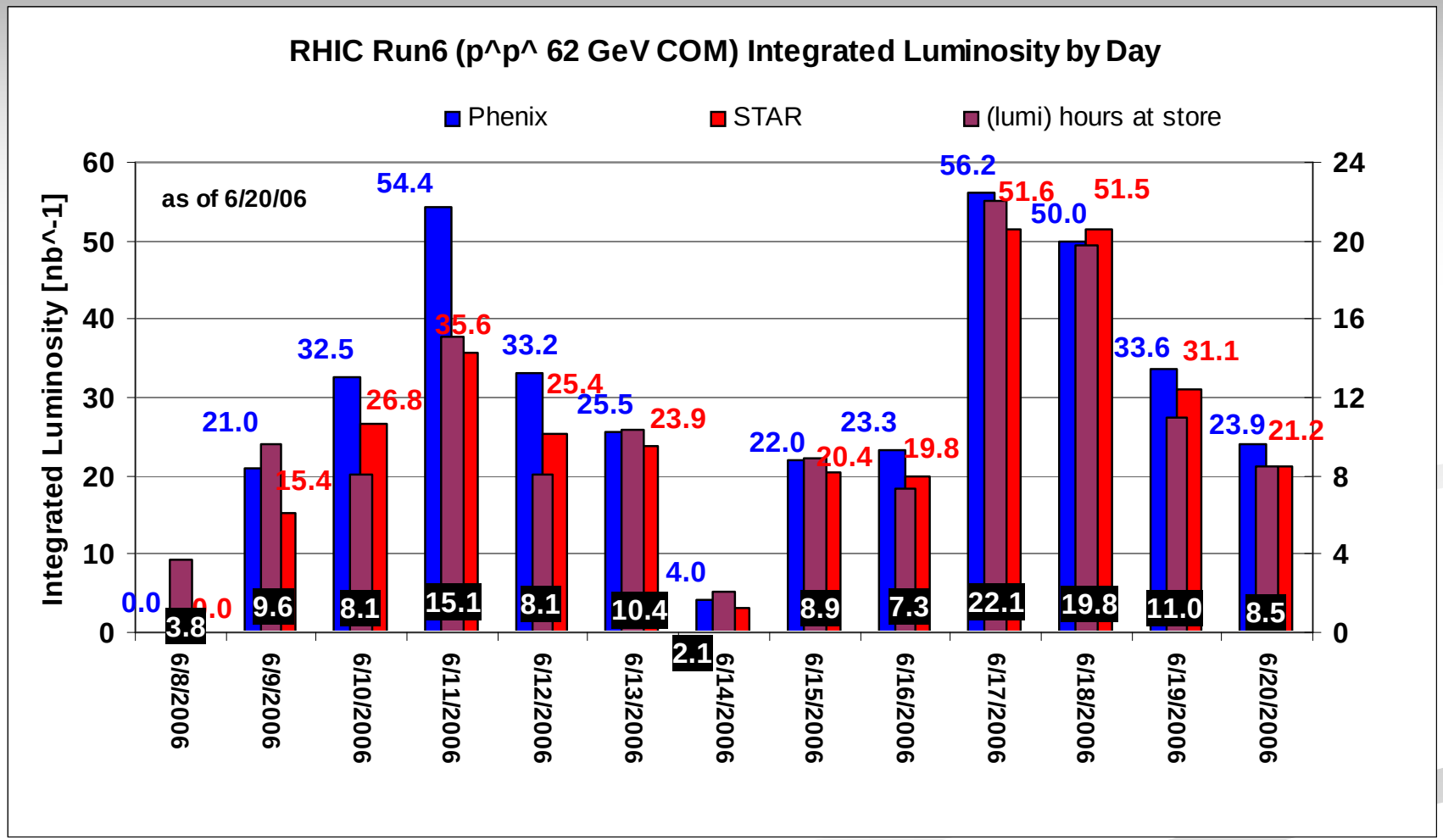
- PHENIX vertex reduction.

- Broken “Up” sequence, because of the need for the manual orbit correction.
- The same ‘store’ stone before and after the cogging. So, it should provide the good lifetime with/without collisions at different working points. (There is tune shift both due to beam-beam and the IR bump removal) .
- BPM offsets in some triplets are still large ( >1mm).
- Model: tune/decoupling shifts versus orbit changes

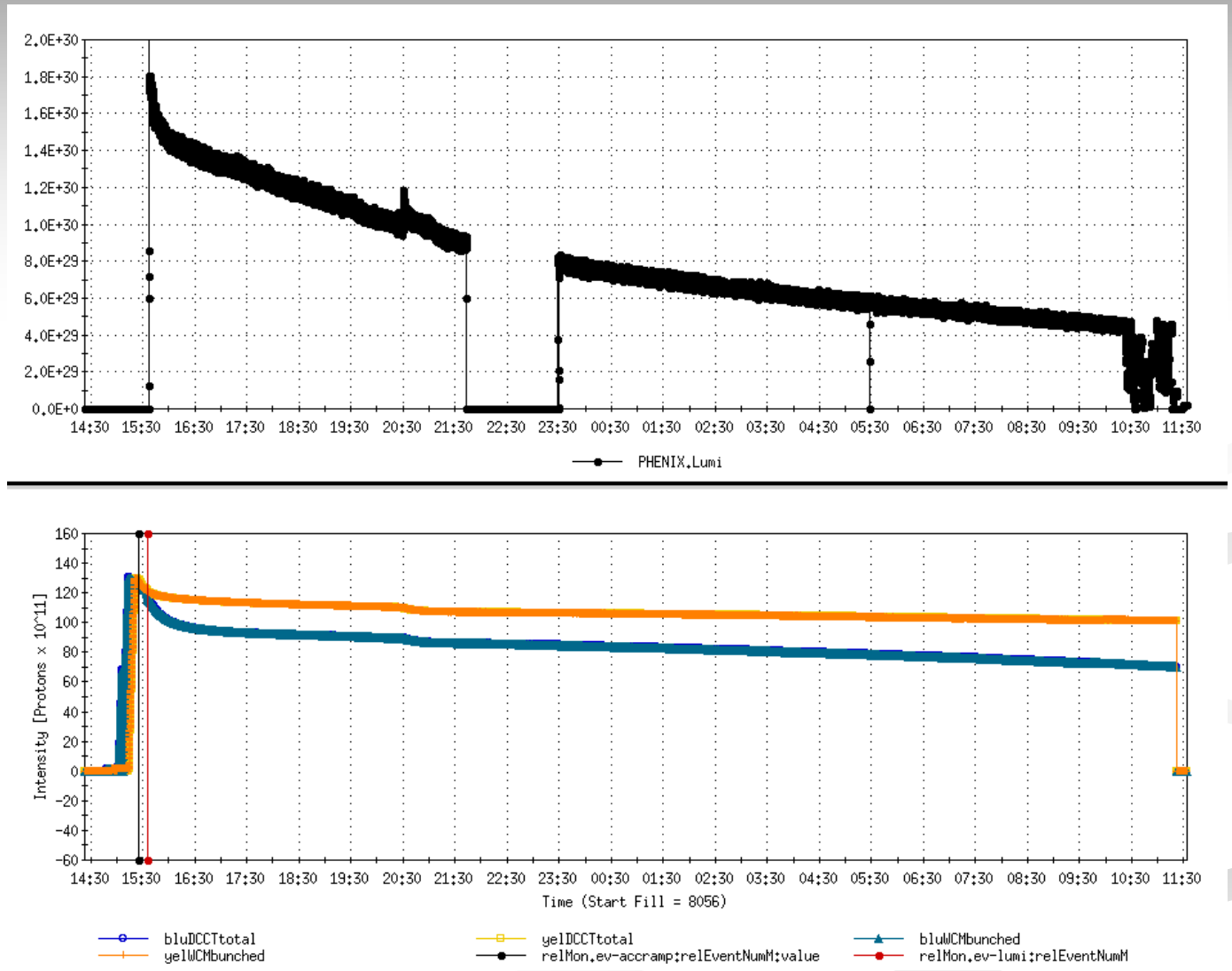
# Integrated luminosity; 31.2 GeV run



# Integrated luminosity by day; 31.2 GeV run



# Golden store (#8056) of 31.2 Gev run, with rotators



# Luminosity improvement factors for next run

Goal: doubling the luminosity, by bunch intensity increase and increased time in store

- Nonlinear chromaticity correction
- 10Hz IR orbit feedback
- 2/3 resonance compensation
- New working point test, ~(0.92;0.93)
- Additional NEG pipes (~45m)

- Reliability of various machine systems is seriously addressed in this shutdown.

- In more remote plans the application of new 9.3Mhz RF cavity system is considered (M.Brennan).

  This should allow for smaller longitudinal emittance with smaller bunch length in the store, but long enough bunch length at the injection.